

IEEE Std. C57.100

IEEE Standard Test Procedure for Thermal
Evaluation of Liquid-Immersed
Distribution and Power Transformers

11:00 am to 12:15 am
Monday, 20 March 2006
Emerald 1 Room
The Hilton Hotel
Costa Mesa, CA

Agenda

- 1. Introduction and Rosters**
- 2. Approval of Minutes from 24 October 2005 Meeting**
- 3. Discussion of existing two methods in existing C.57.100 document – Lockie tests and sealed tube tests.**
- 4. Discussion of First portion of DuPont – Weidmann test of Model with Thermally Upgraded Kraft.**
- 5. Open items from last meeting**
 - a. IEC document (62332) – still need to get approval for use.**
 - b. Search for other applicable IEC documents.**
- 6. Assign work elements for the revision of C57.100.**

Existing C57.100 Methods

7.1 Distribution transformers

Test samples should be complete transformers and should be typical of the design being evaluated insofar as insulation structure and processing, liquid content, and manner of sealing are concerned. A minimum of three samples should be tested at each test temperature.

The test procedure involves subjecting the test samples to repeated test periods consisting of the following two parts:

- a) Exposure to elevated temperature while excited at rated voltage; and
- b) Application of end-point tests to determine end of life, as defined in Clause 5.

5. Criteria for end of life

In this test, the life of a particular test specimen is considered to be ended when thermal degradation has progressed to a point such that the specimen cannot withstand any one of a series of tests intended to simulate the abnormal currents or voltages that are commonly experienced in actual service. The degradation or aging is produced by a series of temperature cycles, each consisting of a specified time at a specified hottest-spot temperature followed by a return to approximately ambient temperature. Such a series of temperature cycles, followed by end-of-life tests, will hereafter be referred to as a *test period*.

Sealed Tube Method (Annex)

Standard test procedure for sealed tube aging of liquid-immersed transformer insulation

A.2 Test samples

The test tubes are typically of stainless steel, but alternatively may be of glass. The tubes are typically about 28 cm long with an inside diameter of 4.0 cm, and a wall thickness of 5.0 mm. The tubes have gasketed screw-on caps and may be fitted with a valve for venting.

The insulation shall be dried to approximate the treatment that is used for a full scale transformer. A minimum moisture content of 0.25% and a maximum of 0.50% by weight of solid insulation is required as measured by the Karl Fischer method.

The insulation in each tube should be apportioned to approximate their relative content in a full-scale transformer. An appropriate air or gas space should be left in each tube, and a minimum of four samples shall be aged at each temperature.

DuPont- Weidmann Test

- Review of purpose of test from last meeting
- Findings to Date
- Next Steps in Testing
- Evaluate test methodology to determine use as an IEEE method.

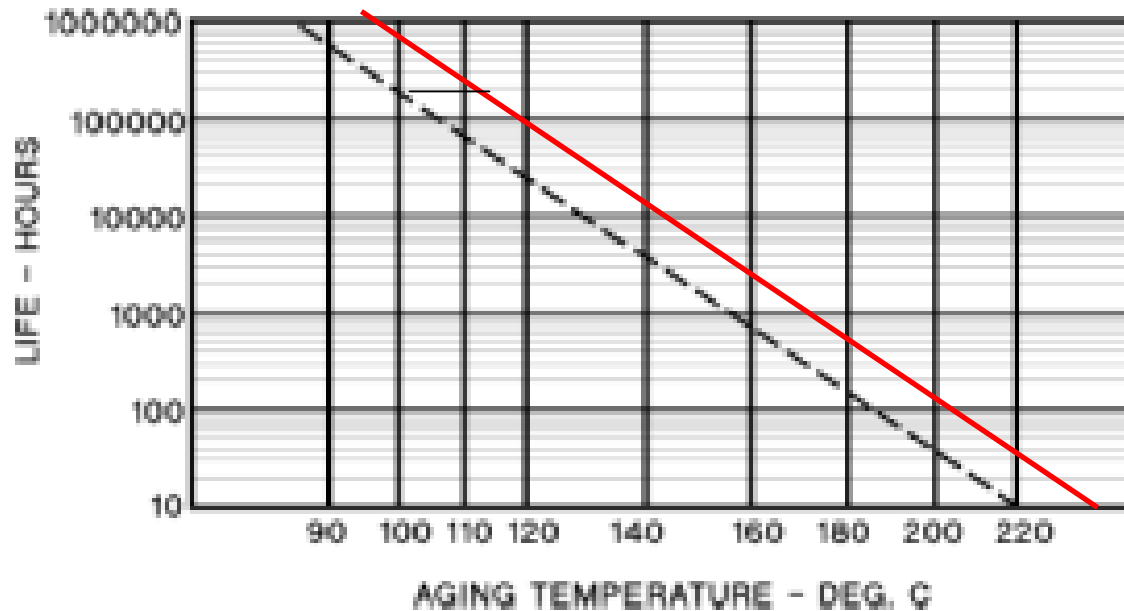
DuPont – Weidmann Test

Purpose – Utilize the IEC 62332 methodology to evaluate thermally upgraded kraft – comparing results to historical data presented in C57.100.

Products to test: Range of kraft papers from 0% Nitrogen (non-upgraded paper) to 2.74% Nitrogen content (Insuldur) [0, 1.0, 1.6, 2.48 and 2.74% N₂]

Will evaluate the conductor insulation using mechanical testing (tensile strength) and DP. Will evaluate spacer material using mechanical testing (compressibility) and DP. Will evaluate bulk oil insulation using mechanical testing (tensile strength) and DP. Will evaluate the oil after aging with DGA, moisture, furans, etc.

DuPont – Weidmann Test



Compare data from this model to other aging curves (distribution transformers, sealed tube test).

Later, Compare existing insulation system with proposed system to determine allowable hottest spot temperature.

DuPont – Weidmann Test



Findings to Date

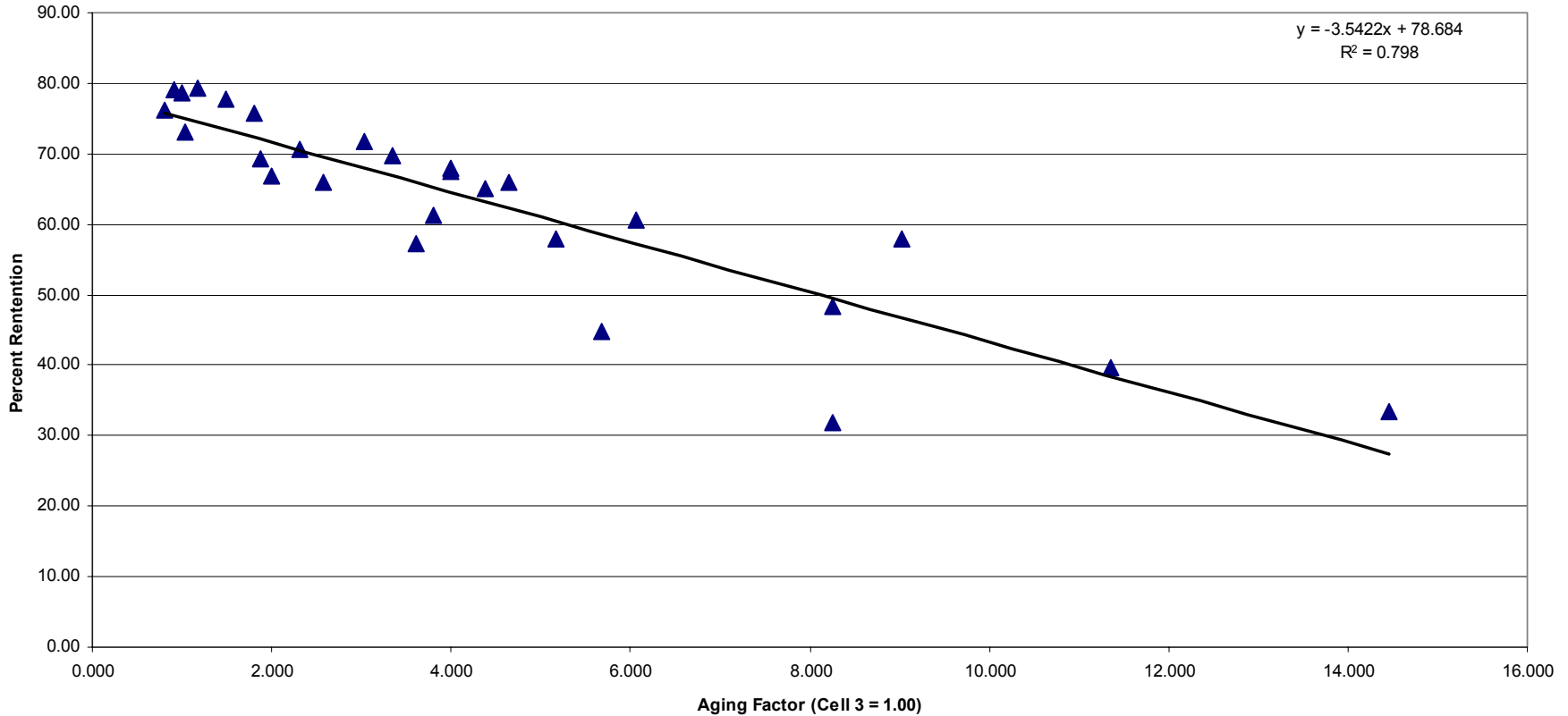
- Aging periods to reach 50% tensile much longer than expected based on historical sealed tube and even Lockie testing
- Initial test plan called for completion of non-upgraded paper and one-temperature comparison of all four N₂ level papers by this meeting. Due to duration of test, the aging time will take more.
- Subsequent aging can be shortened by running at higher temperatures.

Non-Upgraded Papers testing

- Original Plan called for aging up to 62 days at 140°C, with expected $\frac{1}{2}$ tensile point at around 40 days.
- Current test plan has aging going over 500 days, with expected $\frac{1}{2}$ tensile point at around 300 days.
- Original plan called for aging at 140, 148, 156 and 164°C.
- Current plan continues this aging, with some longer points needing to be started over, and conducting testing at 172 and 180°C. Just started four new long running cells at 148, 156 and 164°C (up to 5500 hours).
- Getting a good correlation between DP and % Tensile Retention.

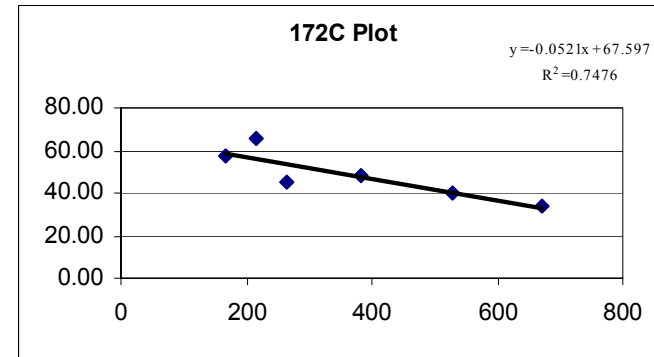
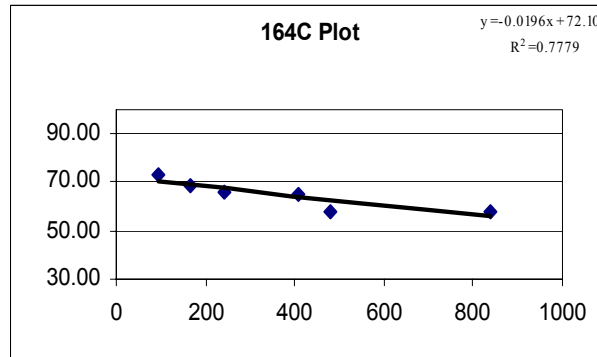
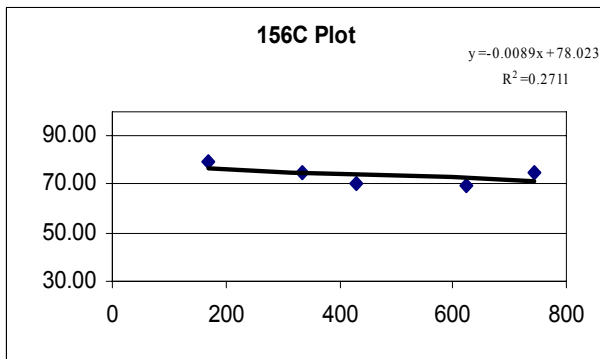
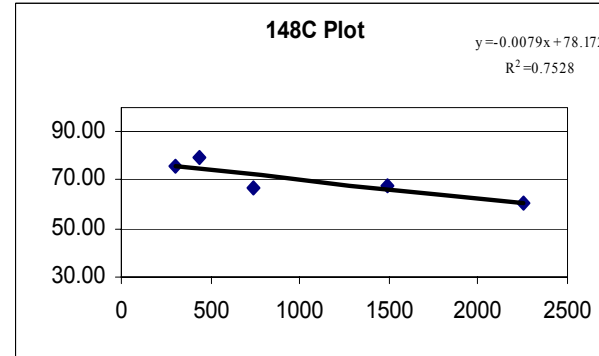
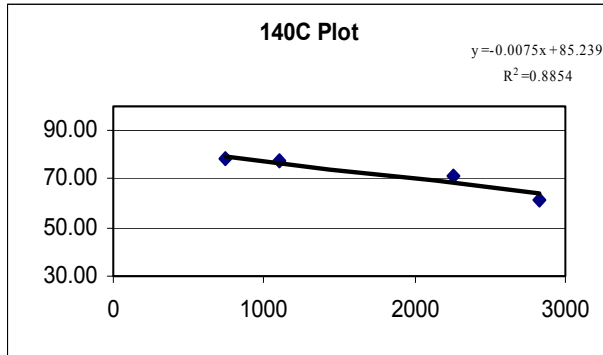
Per Unit Results

Retention vs. Aging Factor (@PU -8)



Method allowed for adjustments to aging times. Will also allow a comparison between different tests. 1.0 per unit was 140°C/744 hours

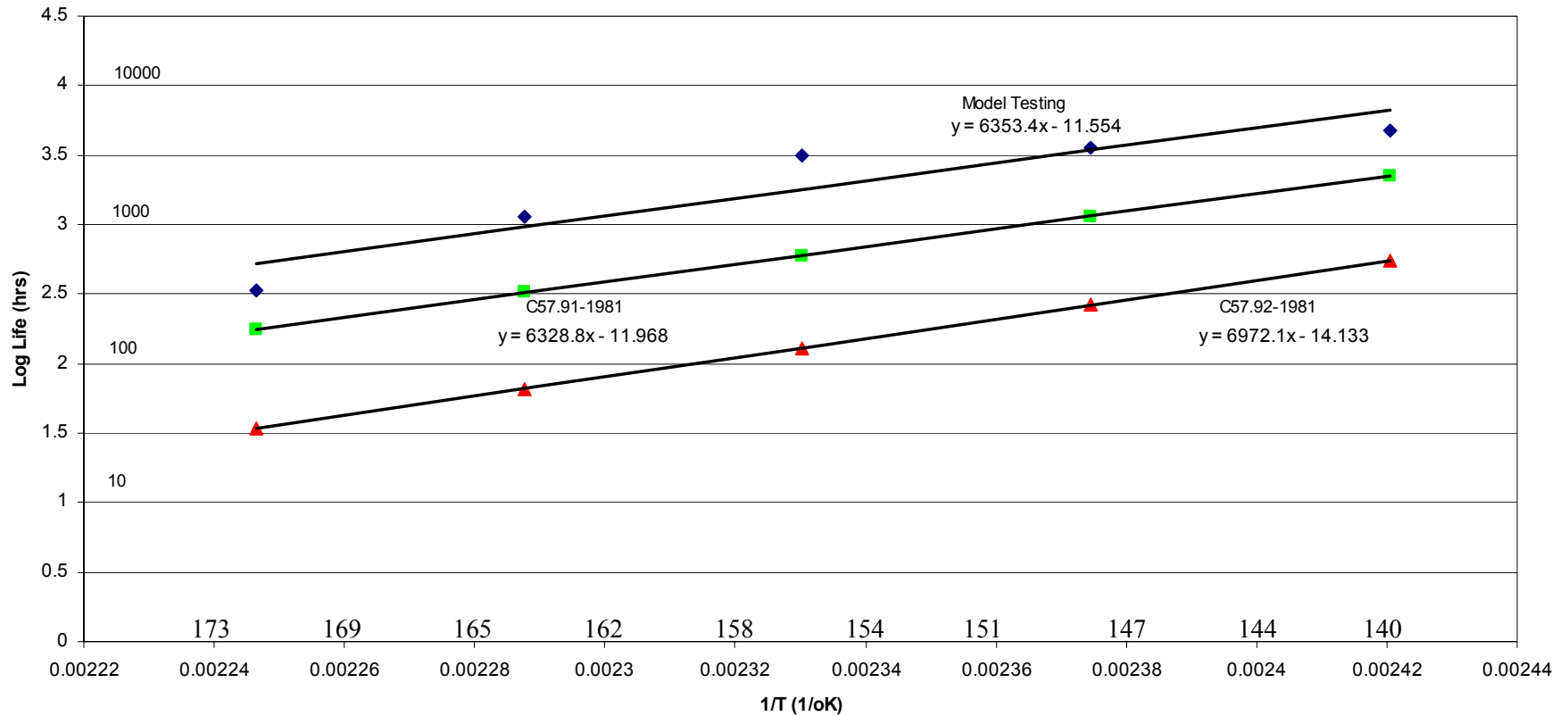
Temperature Plots



	slope	intercept		50% point
140	-0.0075	85.239	50.000	140
148	-0.0079	78.172	50.000	148
156	-0.0089	78.023	50.000	156
164	-0.0196	72.104	50.000	164
172	-0.0521	67.597	50.000	172

Initial Aging vs. Historic Life Curves

Comparison of Aging Methods - Non-upgraded kraft



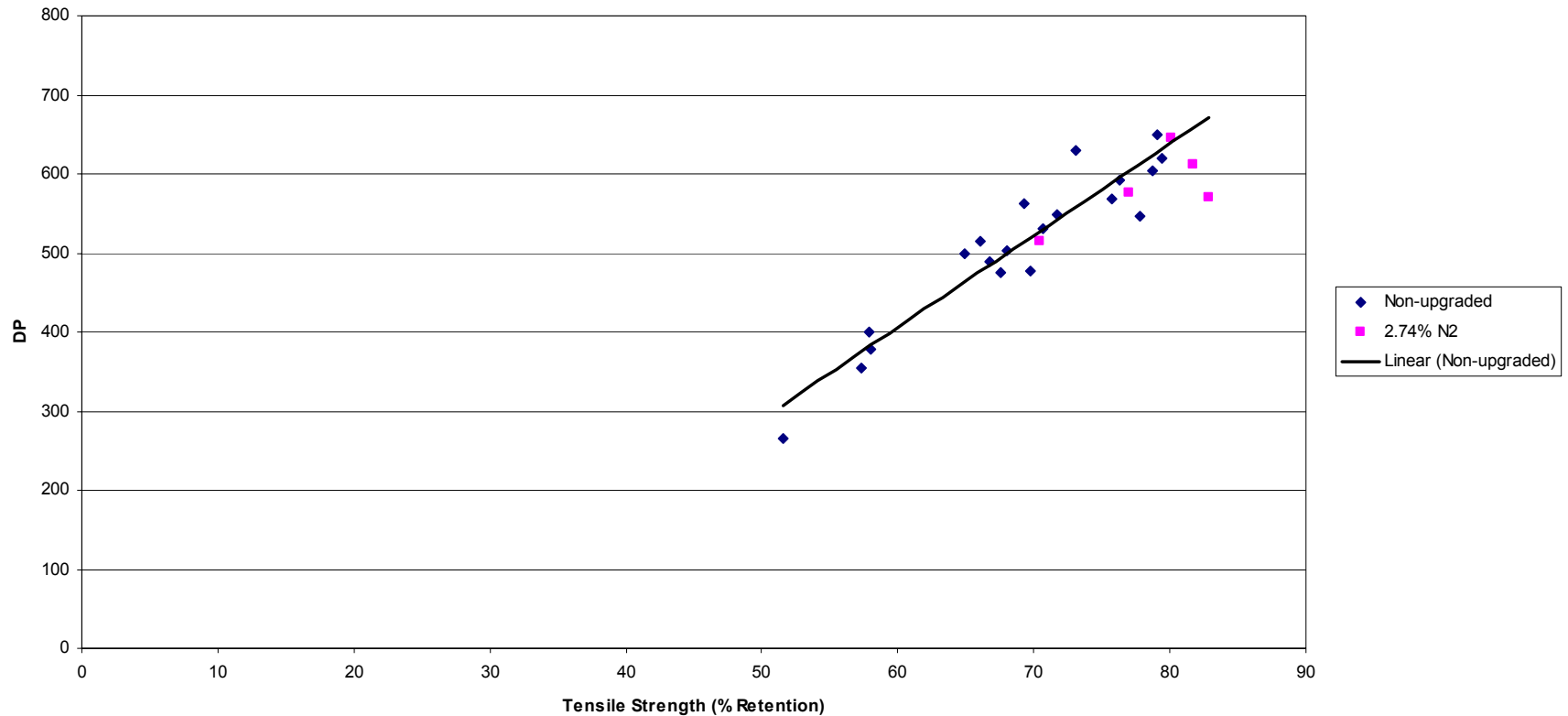
Comparison of New Method to Sealed Tube

Conducted a single test (so far) using a sealed tube with the same set up of conductors/pressboard with $\frac{1}{2}$ the amount of material. Test conducted at 148C and 336 hours.

- Tensile Strength Retention = 68%
- Predictions – Old C57.92 curve = 50% @ 264 hrs.
Old C57.91 curve = 50% @ 1147 hrs.
- New Model tests had close to this retention at both 744 and 1448 hours
- Oil Data had following results:
IFT – 31.1, Acid No. – 0.085, Color L0.5,
Dielectric Strength – 38 kV, PF@25C - 0.009,
Viscosity@ 100F – 98.064

DP vs. Tensile – Paper Samples

DP vs. Tensile Strength Retention

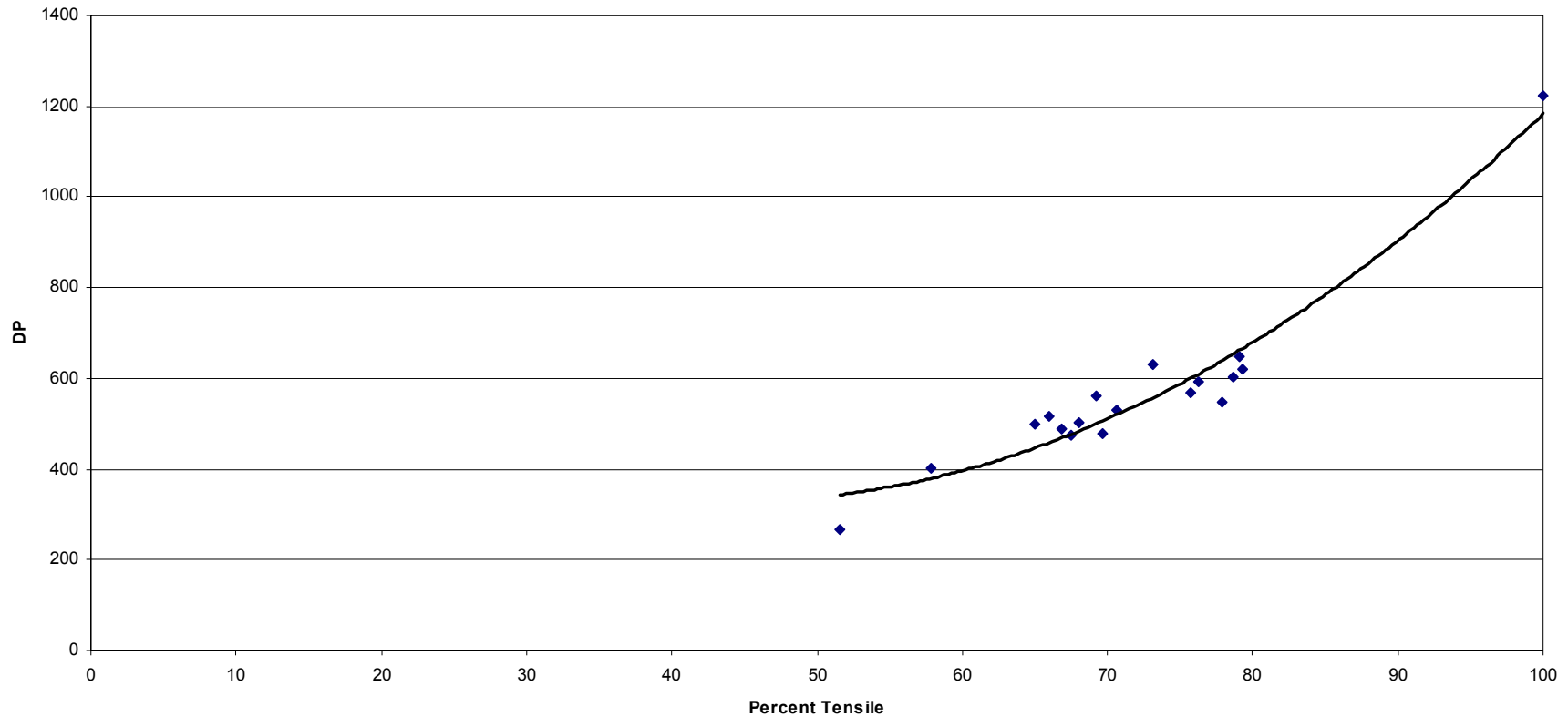


DP of un-aged non-upgraded paper - 1224

DP vs. Tensile – Paper Samples

Percent Tensile Strength vs. DP

$$y = 0.2771x^2 - 24.669x + 879.1$$
$$R^2 = 0.9334$$





Oil Quality

Sample oil with syringe for DGA data and then sample oil after cool-down for oil properties. Oil samples to date have all been very clear with no sludging.

Temperature	Time	Interfacial Tension	Acid Number (mg KOH/g)	Color Number	Visual Exam.	Sediment Exam.	Dielectric Breakdown	Dielectric Breakdown	Power Factor	Power Factor @	Viscosity @ 100°F
		D-971	D-974	D-1500	D-1524	D-1524	D-877	D-1816	D-924	D-924	D-445
140	744	33.2	0.033	L0.5	CLR&SPRK	ND	38	27 (1-21C)	0.004	0.149	62.387
140	1104	36.2	0.015	L0.5	CLR&SPRK	ND	34	34 (1-22C)	0.005	0.114	62.183
140	2256	37.7	0.028	L0.5	CLR&SPRK	ND	33	31 (1-23C)	0.002	0.121	54.519
148	300	34.9	0.058	L0.5	CLR&SPRK	ND	40	33 (1-21C)	0.42	1.395	61.445
148	434	34.6	0.035	L0.5	CLR&SPRK	ND	36	26 (1-23C)	0.011	0.512	79.512
148	744	32.3	0.113	L0.5	CLR&SPRK	ND	39	35 (1-22C)	0.015	1.012	61.327
148	1488	35.8	0.015	L0.5	CLR&SPRK	ND	35	32 (1-23C)	0.004	0.253	63.456
156	168	39.9	0.015	L0.5	CLR&SPRK	ND	35	27 (1-24C)	0.018	0.207	60.399
156	336	32.2	0.024	L0.5	CLR&SPRK	ND	33	27 (1-22C)	0.118	0.704	61.584
156	431	42.1	0.029	L0.5	CLR&SPRK	ND	38	37 (1-24C)	0.009	0.272	79.638
156	624	35.4	0.014	L0.5	CLR&SPRK	ND	37	28 (1-24C)	0.005	0.198	57.945
156	744	34.9	0.033	L0.5	CLR&SPRK	ND	38	30 (1-22C)	0.006	0.558	63.624
164	96	35.4	0.013	L0.5	CLR&SPRK	ND	33	32 (1-24C)	0.009	0.285	61.347
164	168										
164	240	36.2	0.025	L0.5	CLR&SPRK	ND	38	26 (1-23C)	0.005	0.062	59.695
164	408	35.8	0.023	L0.5	CLR&SPRK	ND	37	28 (1-21C)	0.004	0.099	99.569
164	480	33.3	0.024	L0.5	CLR&SPRK	ND	34	27 (1-23C)	0.008	0.319	59.233
164	840	37.5	0.034	L0.5	CLR&SPRK	ND	37	37 (1-22C)	0.002	0.126	55.144

DGA

Temperature	Time	Hydrogen	Methane	Ethane	Ethylene	Acetylene	Carbon Monoxide	Carbon Dioxide	Nitrogen	Oxygen	Total Gas	Total Combusti	Equivalent TCG %	Moisture in Oil
		ASTM D-3612 (ppm)												D-1533B
140	744	0	9	7	1	0	2253	47930	46002	2085	98287	2270	3.1105	8
140	1104	1	37	6	0	0	2014	20819	47294	2872	73043	2058	2.833	8
140	2256	8	26	17	3	0	2163	18509	100969	11218	132913	2217	1.4461	3
148	300	6	129	14	2	0	6557	98122	44308	2254	151392	6708	8.2235	7
148	434	3	22	6	2	2	1340	12789	81472	1835	97471	1375	1.1654	11
148	744	4	152	35	3	0	10601	71767	46220	3235	132017	10795	12.5686	30
148	1488	0	17	6	5	0	267	9349	84037	11470	105151	295	0.2175	5
156	168	24	14	4	2	0	789	11301	70552	6199	88885	833	0.8199	11
156	336	0	8	4	1	0	1577	13502	47696	1977	64765	1590	2.2507	6
156	431	3	23	8	1	0	2609	25499	96343	4009	128495	2644	1.8605	11
156	624	24	29	5	6	0	1437	13346	66795	3914	85556	1501	1.5376	13
156	744	1	60	7	1	0	2980	60286	56185	2400	121920	3049	3.3748	13
164	96	1	21	7	5	0	1805	24629	57640	2630	86738	1839	2.1135	16
164	168													
164	240	3	21	5	6	0	1652	19090	77342	13469	111588	1687	1.3858	14
164	408	8	22	7	3	0	2218	23730	79493	9165	114646	2258	1.8533	18
164	480	24	51	11	4	0	3896	26360	73371	9299	113016	3986	3.4578	16
164	840	8	31	13	3	0	3272	23149	65408	7015	98899	3327	3.2649	7

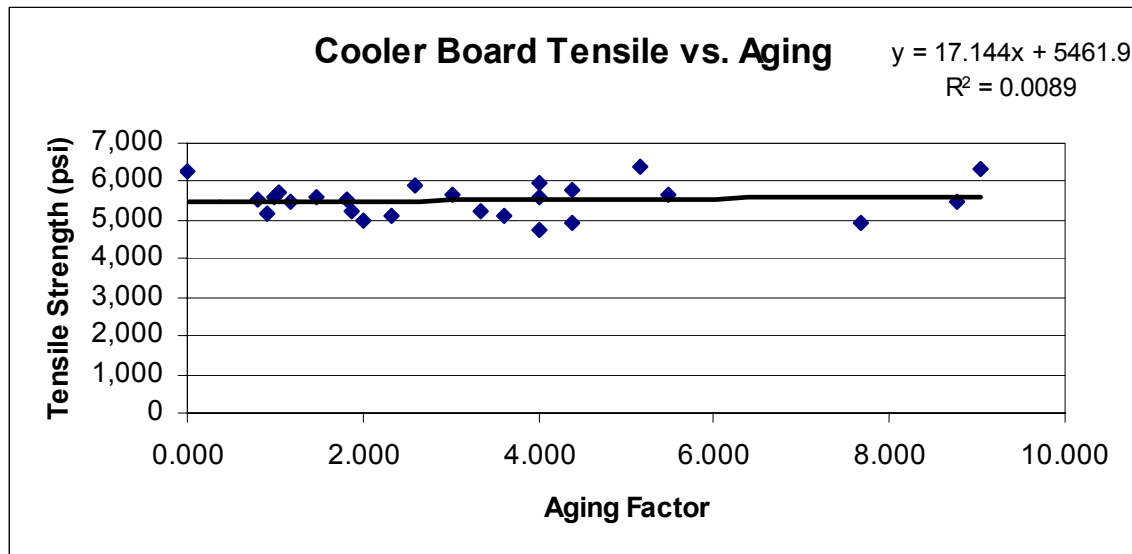
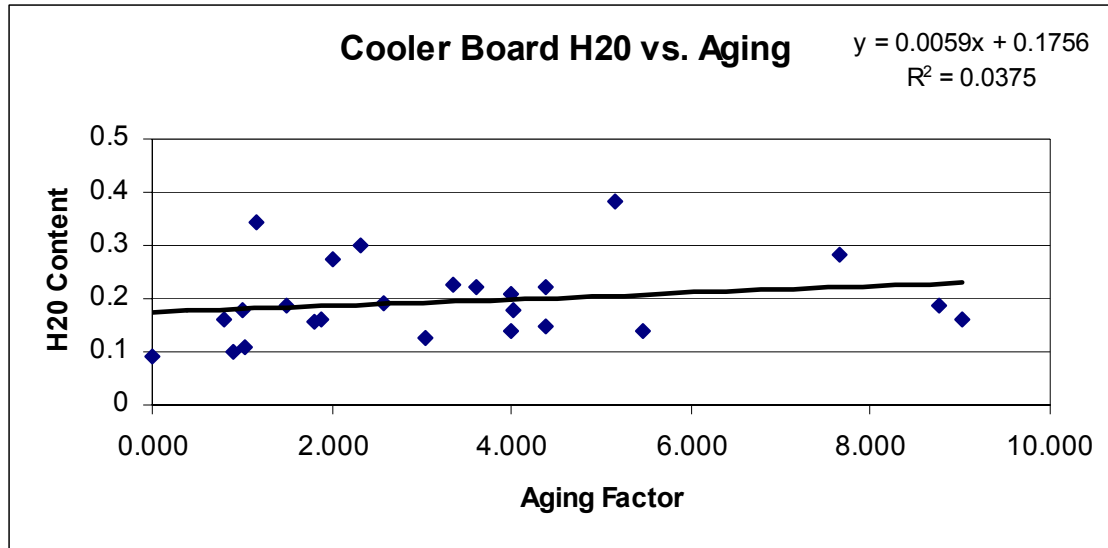
Pressboard Testing

Will evaluate spacer material using mechanical testing (compressibility) and DP. Will evaluate bulk oil insulation using mechanical testing (tensile strength) and DP.

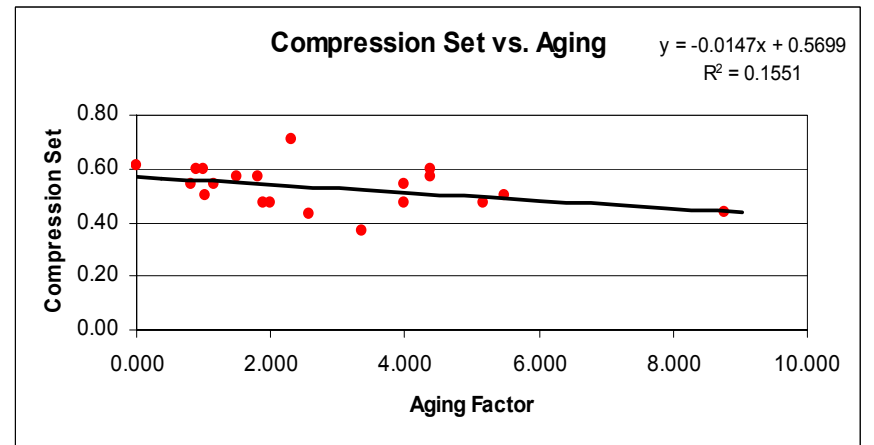
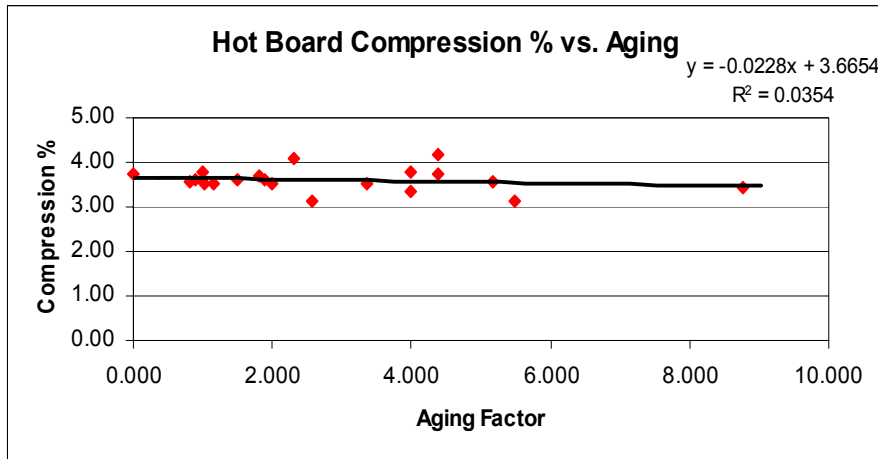
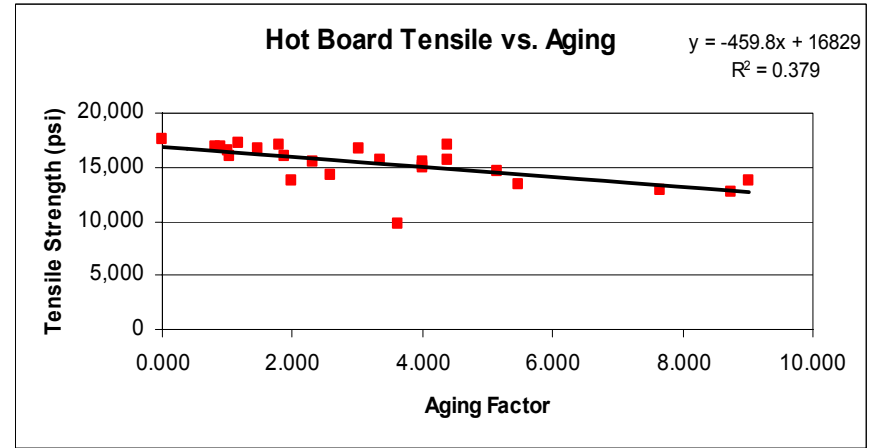
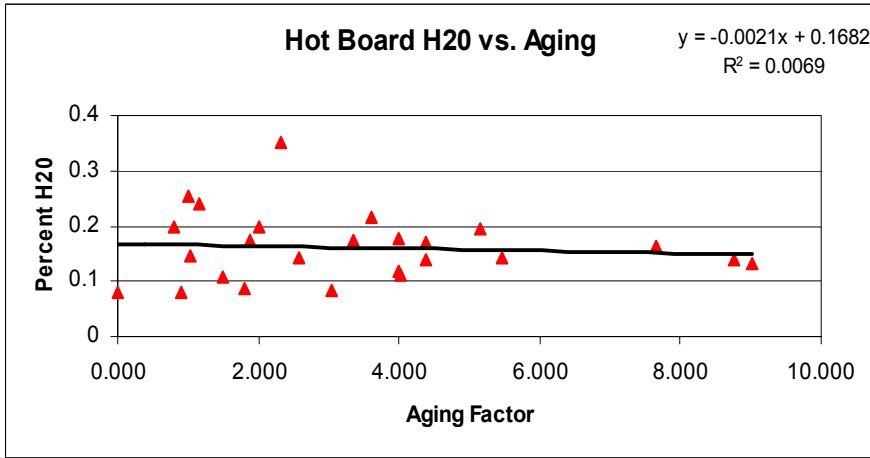
Are starting to get initial results for each.



Cool Board Test Data

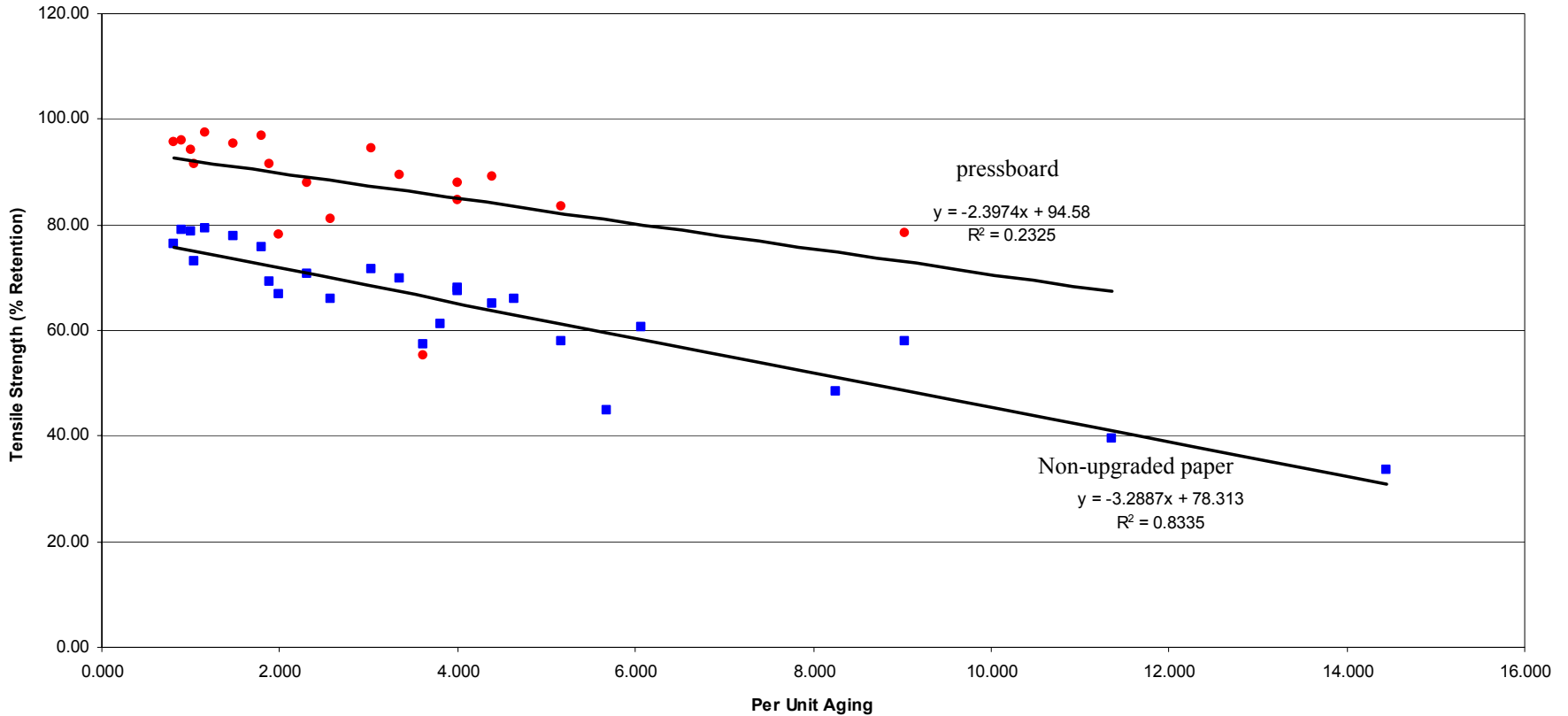


Hot Board Test Data

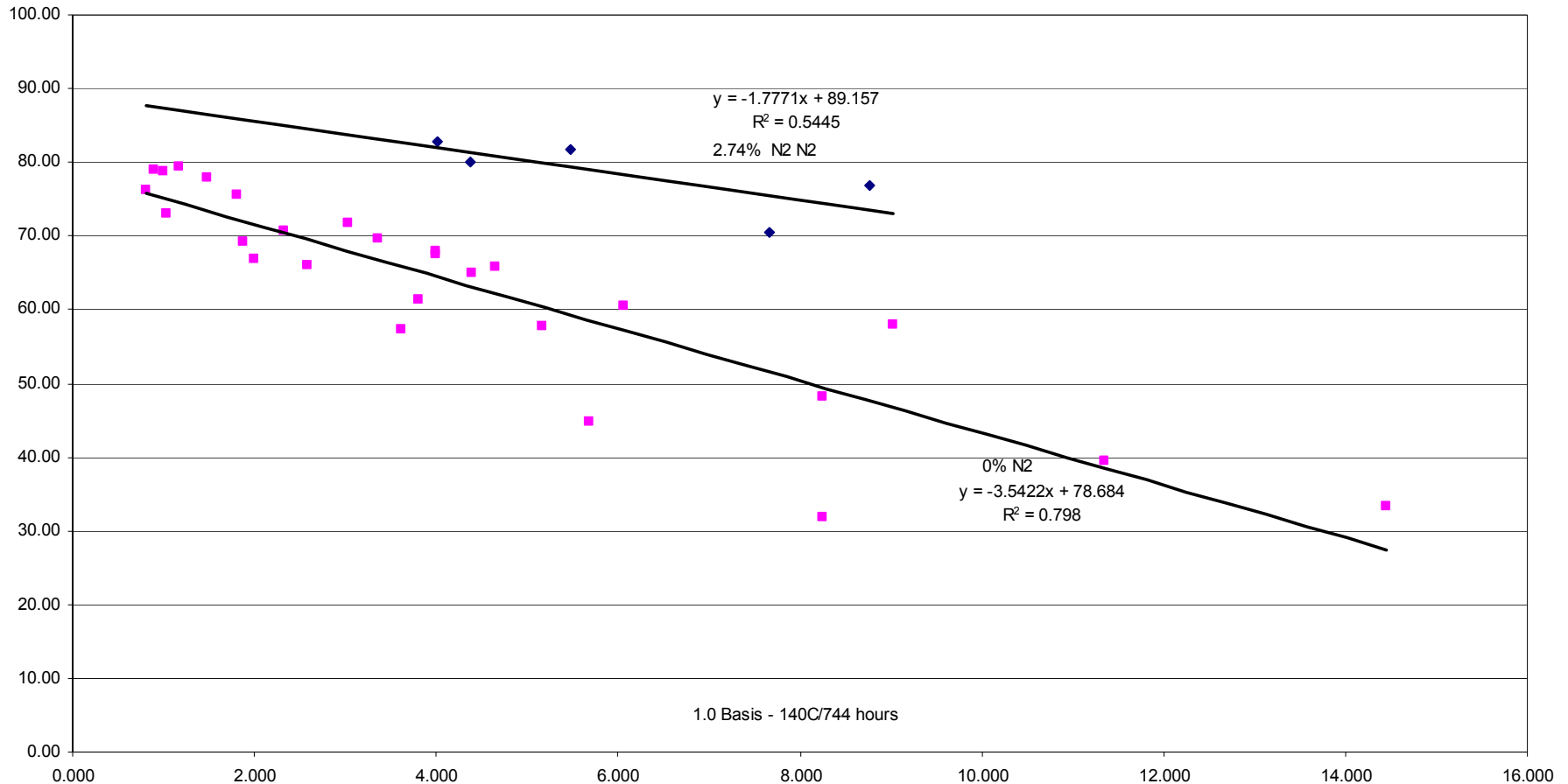


Paper vs. Hot Board Comparison

Paper vs. Hot Board Aging



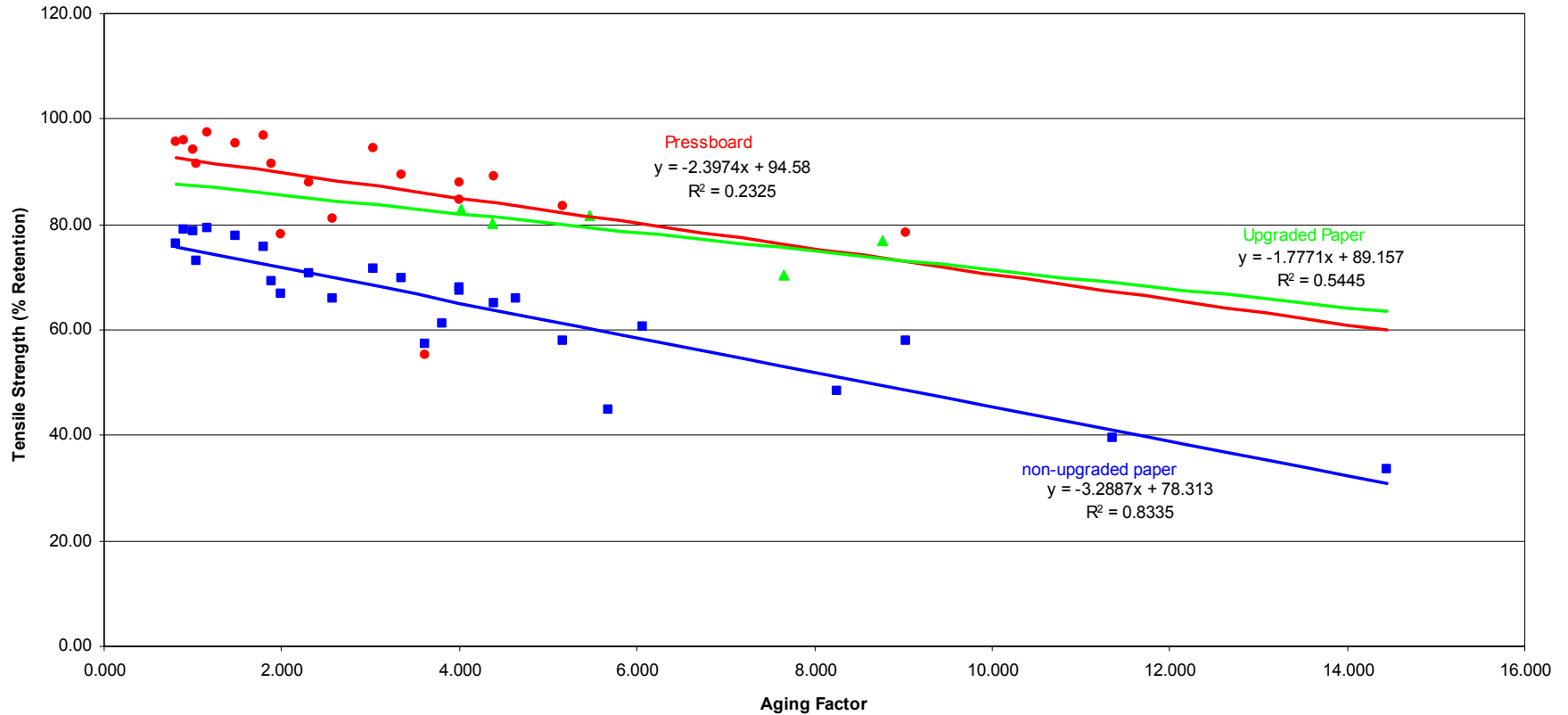
Per Unit Plot – Two paper Types



Limited data points for 2.74% N₂. Still, equivalent life is seen at temperatures around 10C higher than for non-upgraded.

Per Unit Plot – Paper vs. Board

Aging - Paper vs. Board



Next Steps in Testing

- Complete aging of all paper types
- Develop methodology to evaluate the effect of oxygen (bottled gas with known O₂/N₂ content) and moisture (suggestions?).
- Need to understand target levels of oxygen and moisture for evaluation. This may also be needed for other two methods in C57.100.
- Conduct additional sealed tube tests with similar insulation configuration.
- Evaluate what criteria should be used to evaluate systems.

Finish Up meeting